The BTeV Experiment

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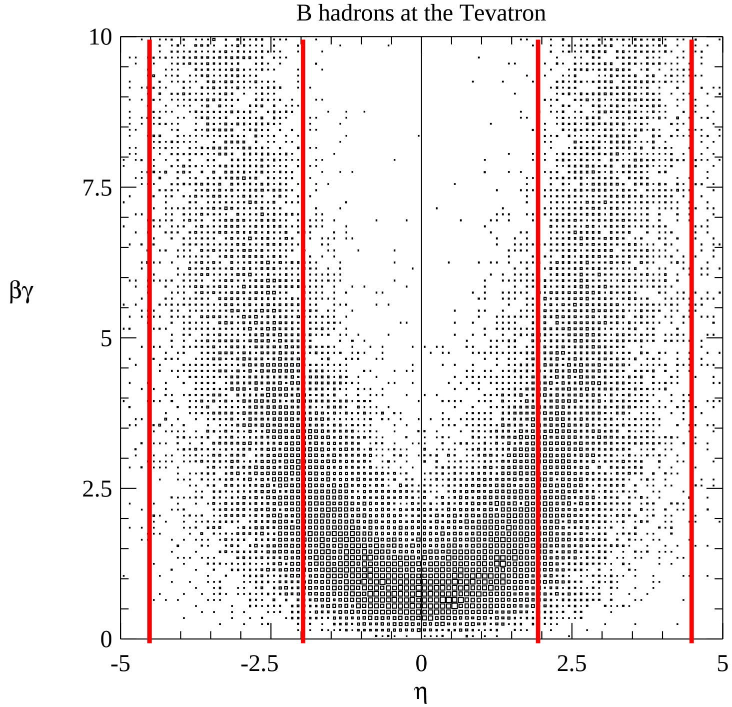
Outline

- B Physics in 2008
- The BTeV Detector
- The BTeV Trigger
- Comparisons with Other Experiments
- Conclusion

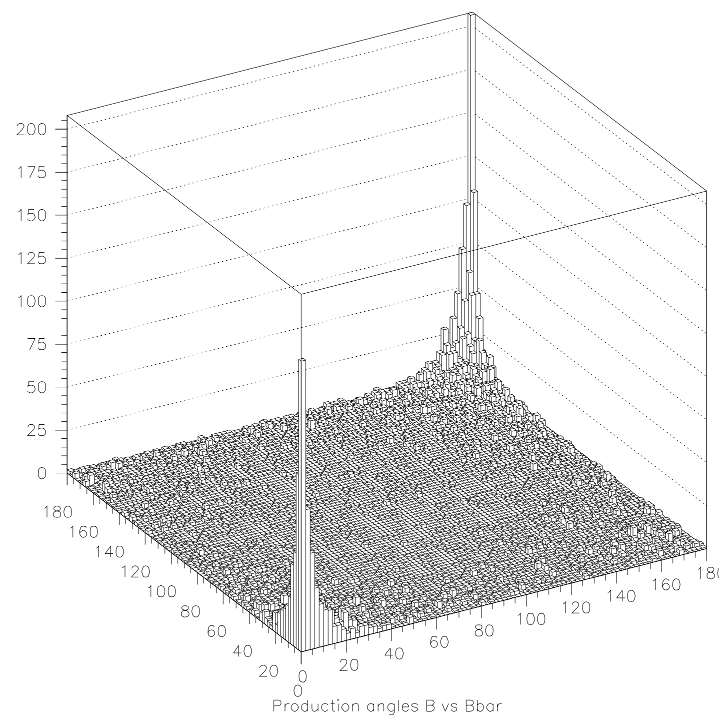
B's in the Forward Direction

- $\sigma(b\overline{b}) \sim 100\ \mu$b, $\sigma(c\overline{c}) \sim 1000\ \mu$b
- Luminosity 2×10^{32}, 132/396 ns spacing $\rightarrow \langle 2/6 \rangle$ int/cross
- $B\bar{B}$ fraction $\approx 2\times10^{-3} \rightarrow 2\times10^{11}$ $B\bar{B}$ pairs/year
- Interaction region $\sigma_z = 30$ cm



BTeV: $1.9 < \eta < 4.5$

Better decay length separation



More $B\bar{B}$ in detector

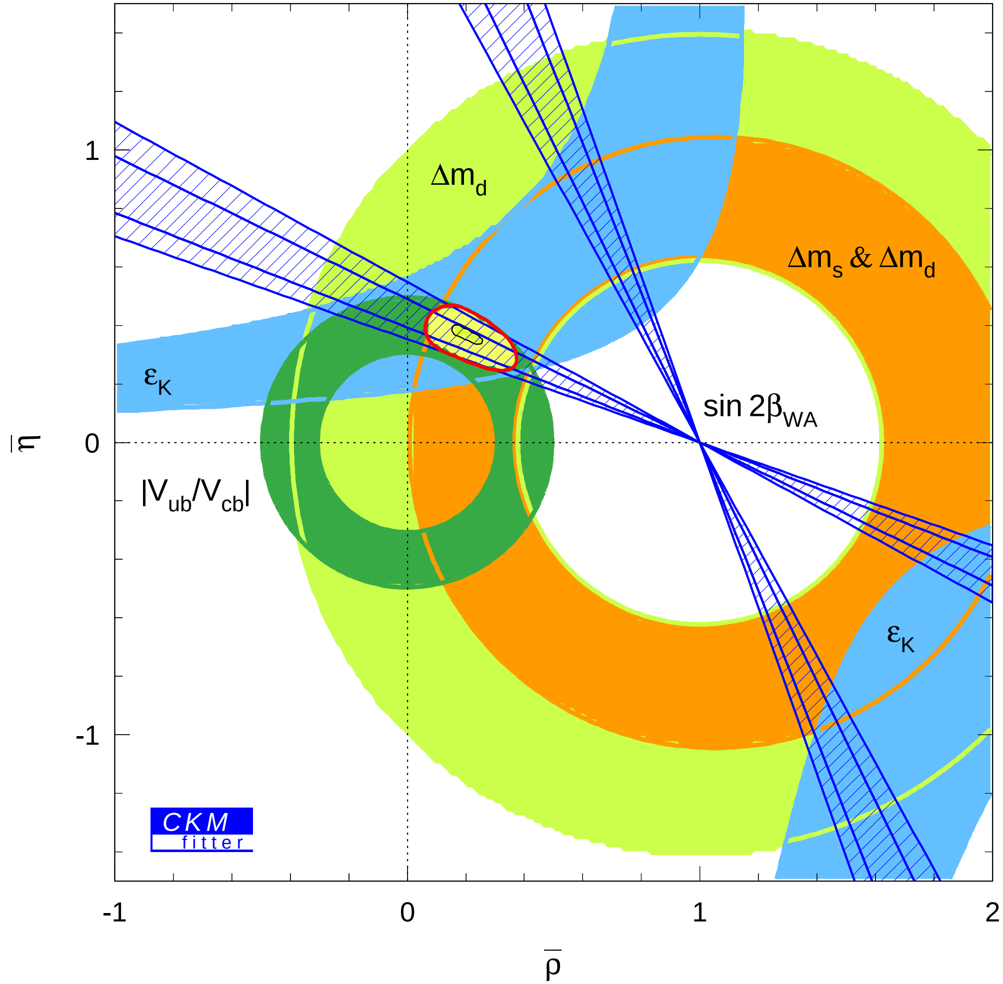
Better opp. side tagging

Status of CKM Measurements

No discrepancies in SM description.
Theory errors dominate except $\sin 2\beta$.

Likely in 2008–9:

- $\Delta m(B_d)/\Delta m(B_s)$ to 5% from CDF & DØ
- $\sin 2\beta$ to 0.02 from 1000 fb^{-1} from BABAR & Belle



BTeV's challenge will be to test CKM as the *only* source of $\not{C}\not{P}$.

Non-SM physics can cause discrepancies in this description.

Measurement Requirements

BTeV provides:

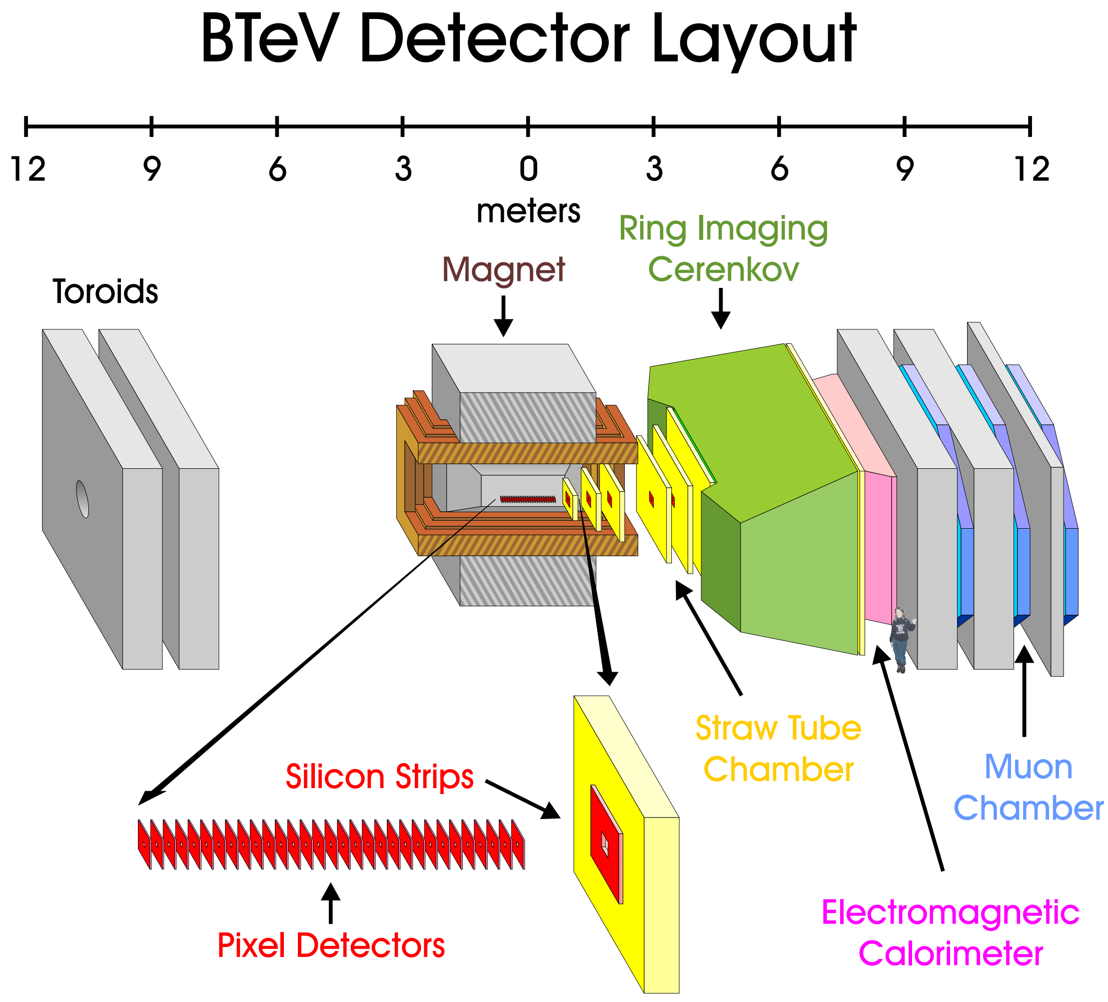
- Large samples of tagged B^+, B^0, B^0_s decays, unbiased b and c decays
- Efficient trigger, well understood acceptance and reconstruction
- Excellent vertex and momentum resolutions
- Excellent particle ID and γ, π^0 reconstruction

Quantity	Decay Mode	Vertex Trigger	K π Sep.	γ Det.	Decay Time σ
$\sin 2\alpha$	$B^0 \to \rho\pi \to \pi^+\pi^-\pi^0$	✓	✓	✓	
$\cos 2\alpha$	$B^0 \to \rho\pi \to \pi^+\pi^-\pi^0$	✓	✓	✓	
$\sin\gamma$	$B^0_s \to D^+_s K^-$	✓	✓		✓
$\sin\gamma$	$B^0 \to D^0 K^-$	✓	✓		
$\sin 2\chi$	$B^0_s \to J/\psi\eta,\, J/\psi\eta'$		✓	✓	✓
$\sin 2\beta$	$B^0 \to J/\psi K^0_S$				
$\cos 2\beta$	$B^0 \to J/\psi K^0, K^0 \to \pi\ell\nu$		✓		
x_s	$B^0_s \to D^+_s \pi^-$	✓	✓		✓
$\Delta\Gamma$ for B^0_s	$B^0_s \to J/\psi\eta^{(\prime)}, K^+K^-, D^+_s\pi^-$	✓	✓	✓	✓

$\sim \frac{1}{2}$ crucial measurements require B^0_s, $\sim \frac{1}{2}$ γ

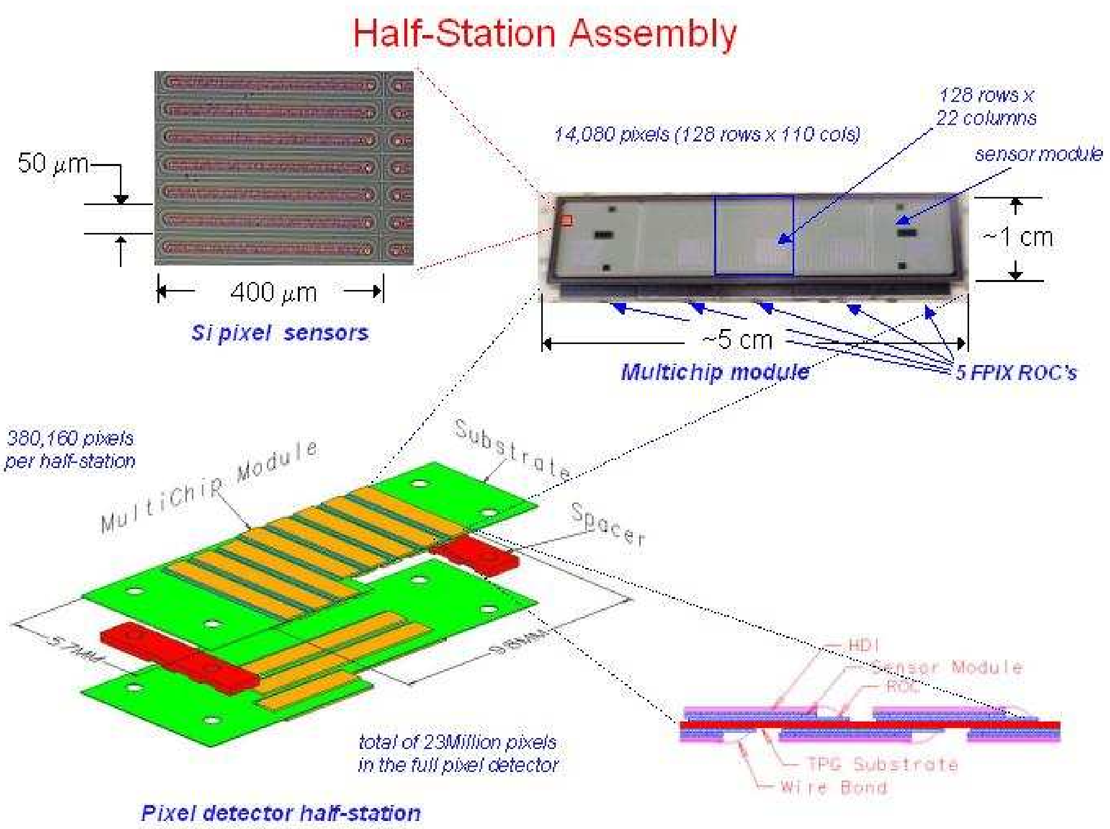
The BTeV Spectrometer

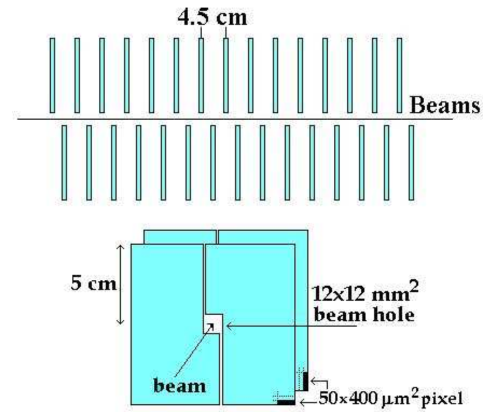
- Collider experiment, but fixed-target-like configuration
- Pixels in magnet, forward tracking with silicon & straws
- RICH particle ID, $PbWO_4$ EM Cal., muon detection

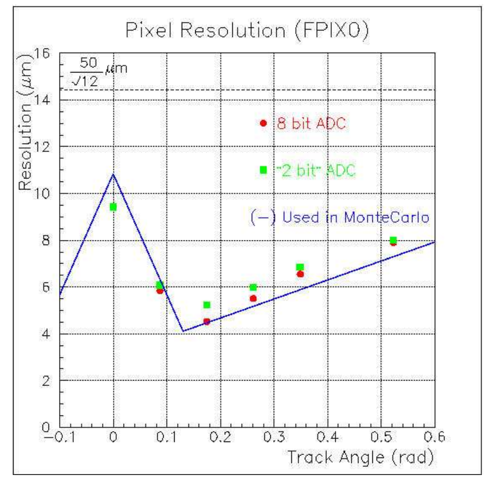


Pixel Vertex Detector

- Pixels are $50 \times 300\ \mu\mathrm{m}$, 20+ million channels
- Rad-hard capabilities demonstrated at IUCF, final readout chip bench tested, will be tested in test beam in 2003
- Demonstrated 5–10 $\mu\mathrm{m}$ resolution in 1999 test beam







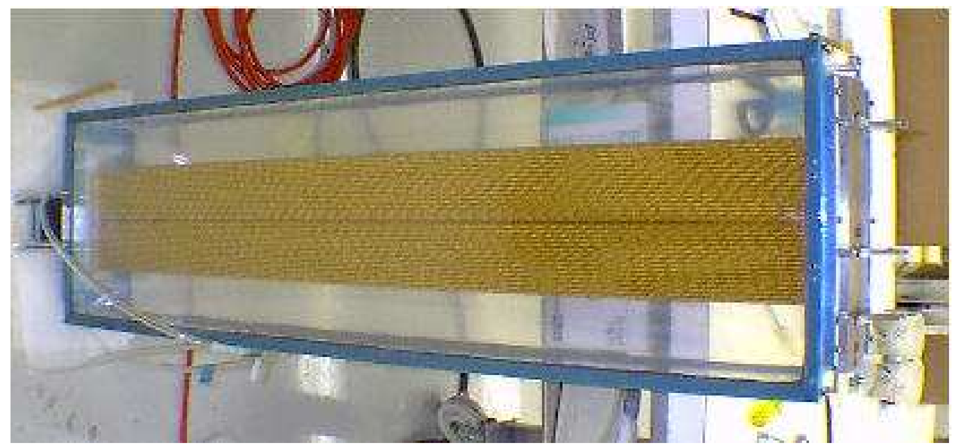
Forward Tracking

7 tracking stations each with

- 100 μm silicon for small angles (high occupancy region)
- 4 mm dia. straw with 27×27 cm hole (3 views, 3 layers)

Simulated performance — $< 1\%$ resolution over all p and θ

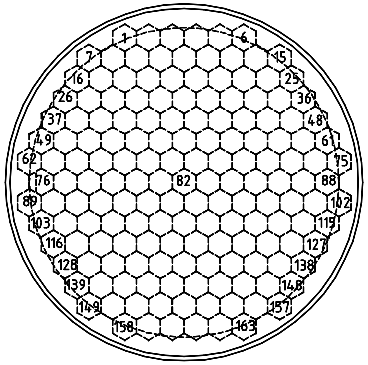
Design for forward tracker

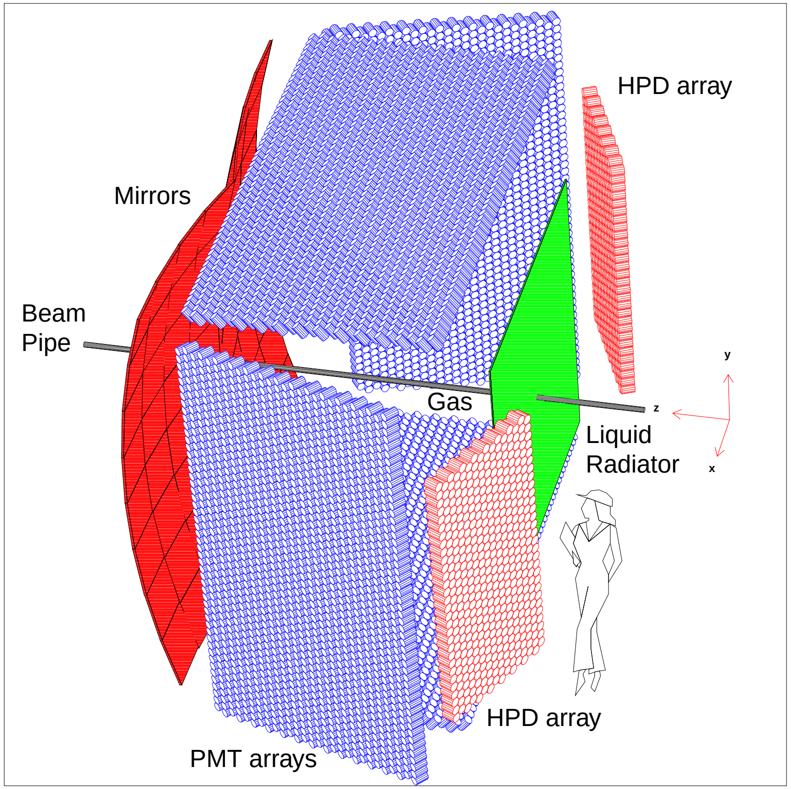


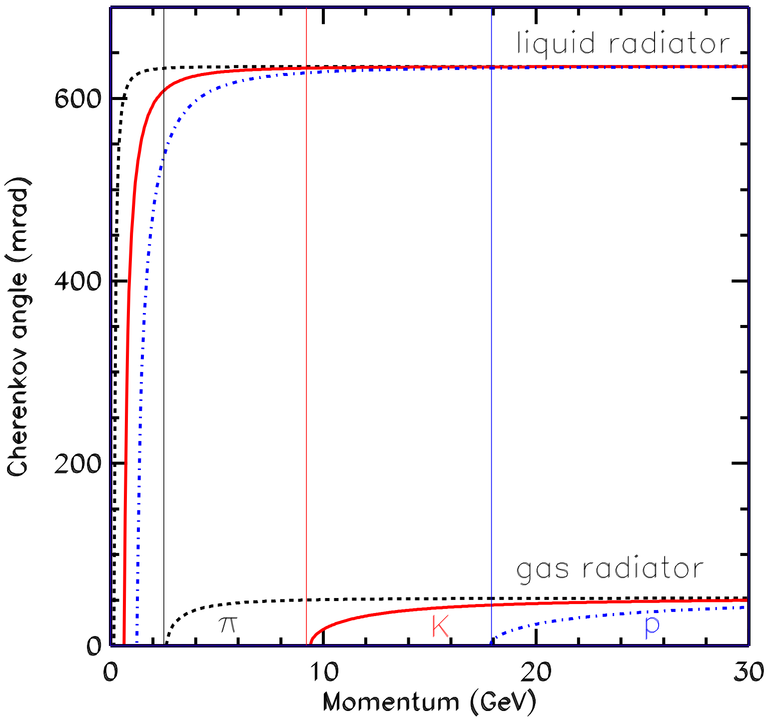
Prototype straw detector
for 2003 test beam

Ring Imaging Čerenkov

- Gas radiator (C_4F_{10}) detected on planes of 163-channel Hybrid Photodiodes
- Liquid radiator (C_5F_{12}) — array of side mounted PMTs (replaced aerogel radiator option detected on same HPDs)

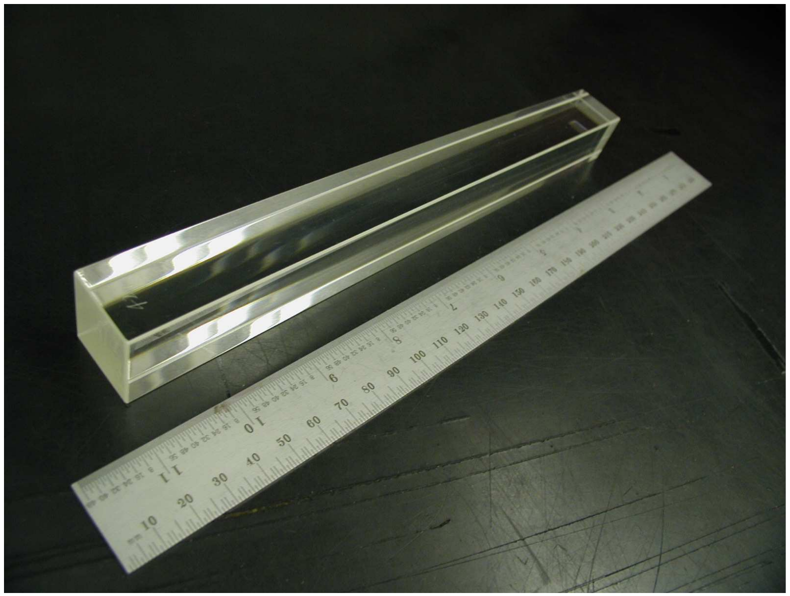




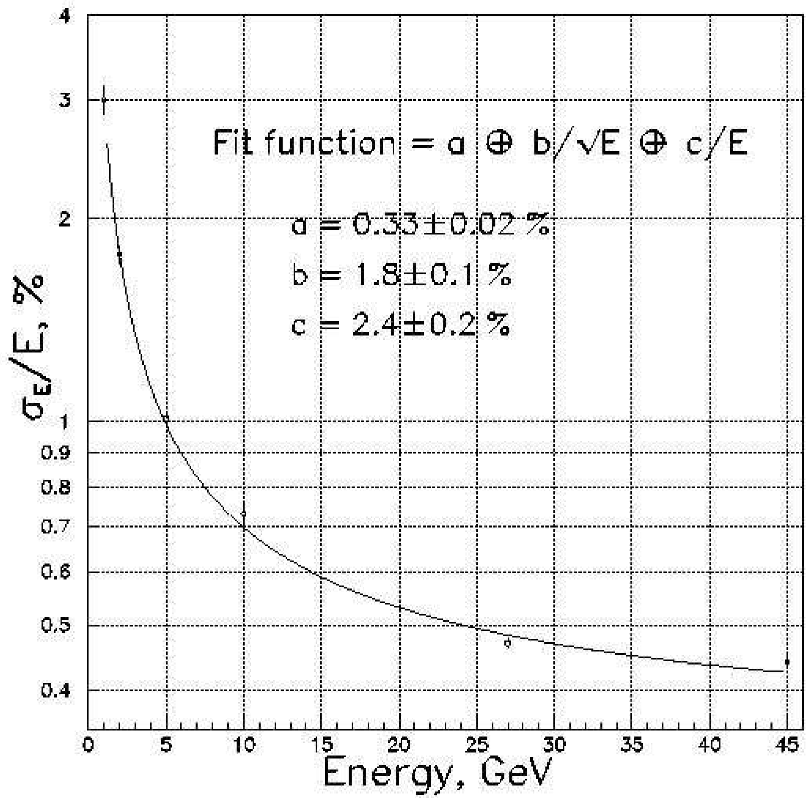


Pb Tungstate EM Calorimeter

- $PbWO_4$ $2.8 \times 2.8 \times 22$ cm crystals pioneered by CMS, but BTeV uses PMTs
- Excellent energy and spatial resolution
- Resolution measured at IHEP/Protvino, stochastic term = 1.8%

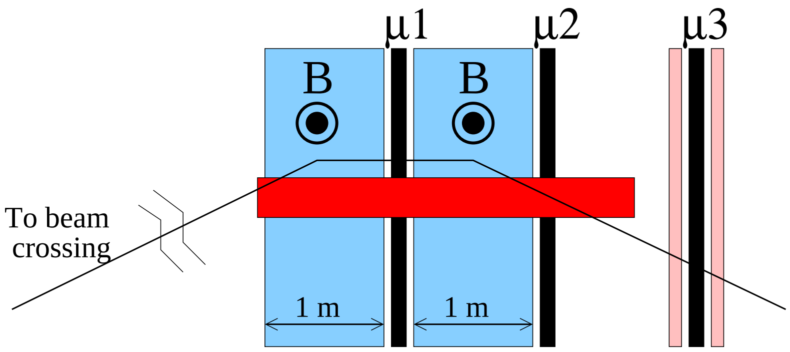


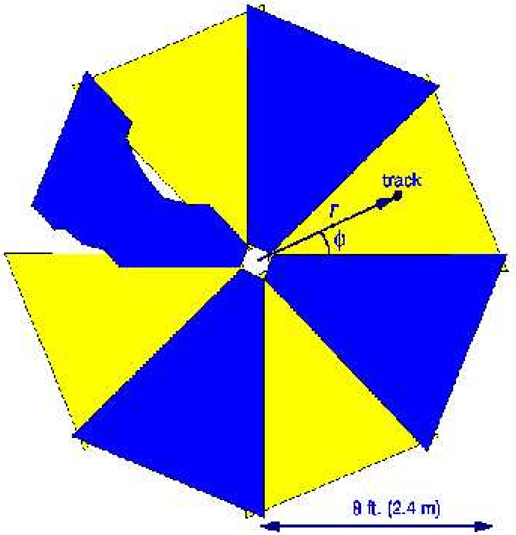
Possible vendors from Bogoridiitsk, Russia and Shanghai, China

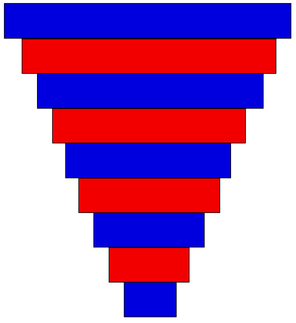


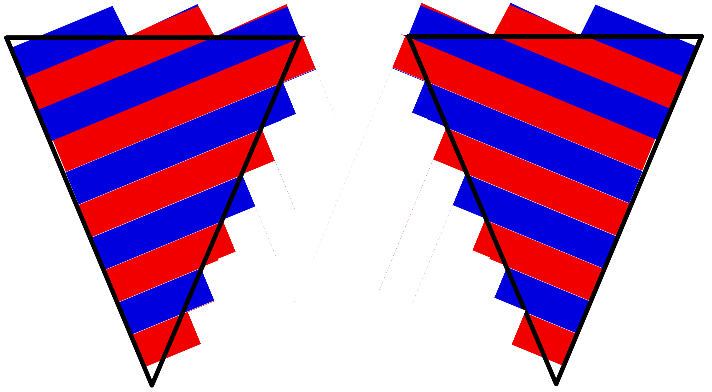
Muon Detector

- Magnetized steel filters and proportional tubes
- 3 stations, 3(4) views/station arranged in pinwheel
- Tested in 1999 beam test, to test again in 2003



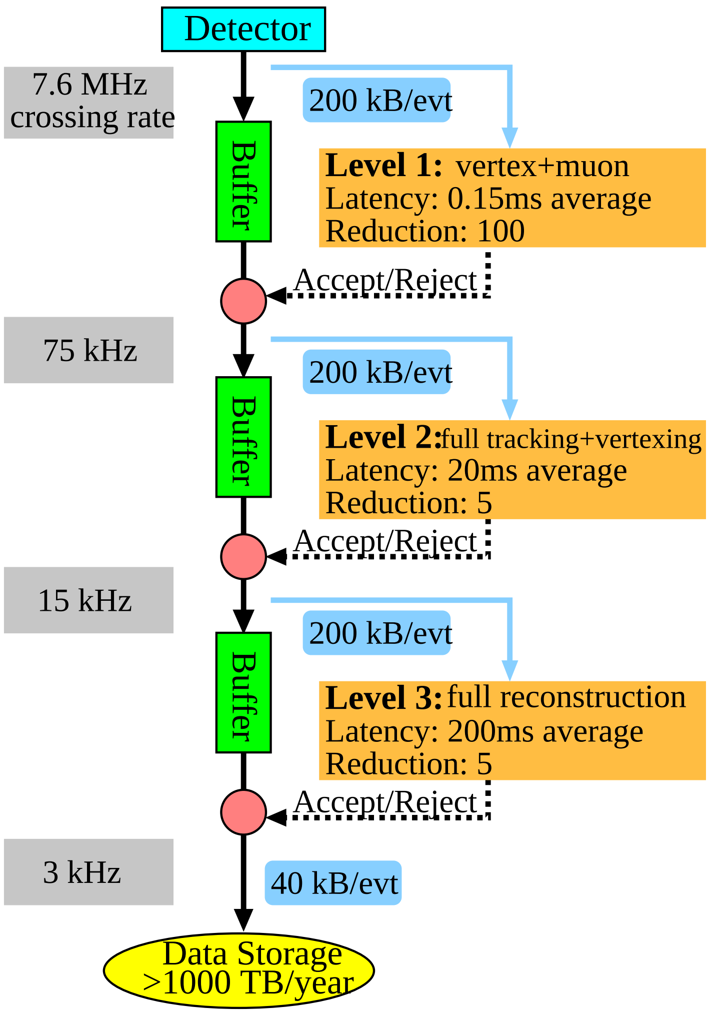




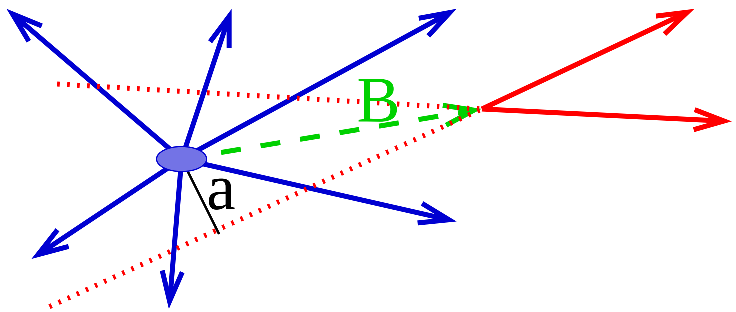


BTeV Trigger & DAQ

Applies computation to every crossing (up to 7.6 MHz)



- Pipelined with 1 TB buffer, no fixed latency
- Level 1: FPGAs and 2500 DSPs find vertices



  - Needs 3D pixel space-points
  - Reconstructs tracks, production vertex (a)
  - Looks for tracks which miss prod. vertex
  - Currently: 2 tracks miss prod. vertex by $> 6\sigma$
- Level 2/3: Farm of 2000 Linux PCs
  - Does fast and then full version of reconstruction

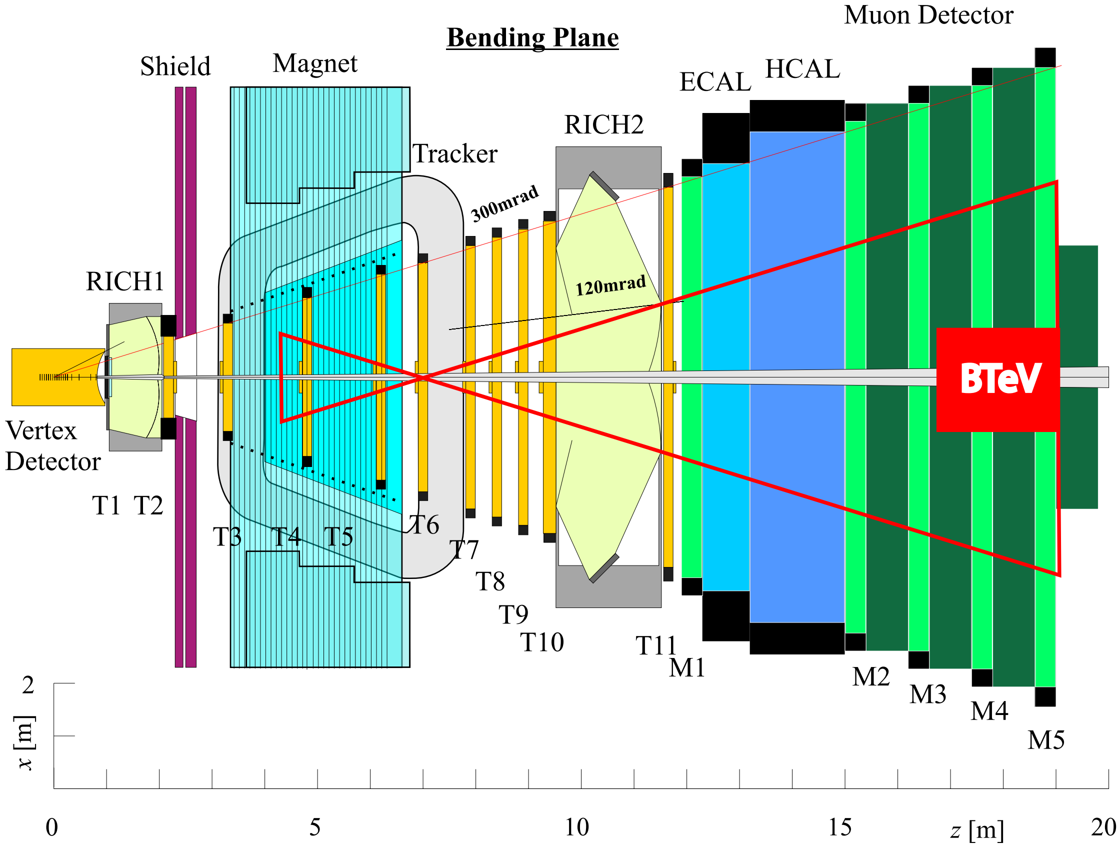
Comparison to LHCb

Strongest competitor to BTeV. Recently re-optimized to reduce material in spectrometer.

LHCb advantages:

- $\sigma_{b\overline{b}} = 5 \times \text{BTeV}$
- $\sigma_{\text{tot}} = 1.6 \times \text{BTeV}$
- $\langle \text{Int./Cross} \rangle < 1$ (25 ns)

But, BTeV has many advantages too.



LHCb before re-optimization

Comparison to LHCb II

- A dipole located *on* the IR gives BTeV a spectrometer covering the forward antiproton rapidity region.
- A precision vertex detector based on planar pixel arrays …
- Enables a vertex trigger at Level 1. This makes BTeV especially efficient for states that have only hadrons.
- A lead tungstate electromagnetic calorimeter for photon and π^0 reconstruction.
- A very high capacity data acquisition system which frees us from making excessively restrictive choices at the trigger level.
  - Unbiased selection of *b* and *c* decays
  - Will have physics that becomes interesting "on tape"
- Result: BTeV is similar in all charged modes, much better in modes with γs, π^0s

History and Status of BTeV

- December 1997: BTeV becomes R&D project
- May 1999: Preliminary TDR
- May 2000: Proposal for 2-arm BTeV, $130M + $50M
  - Unanimously approved by PAC, June 2000
- March 2002: One arm descoped detector proposed, offline computing supplied by universities: $122M + $0M
  - Unanimously approved by PAC
- October 2002: Fermilab (Temple) cost review
- March 2003: Review by P5
- Assuming a positive P5 report, a Temple (internal) and Lehman review will follow
- Construction, commissioning 2007–8, data taking 2009

Conclusions

- BTeV is well positioned to make critical contributions to our knowledge of $\not\!\!{CP}$ and move from initial observations to determining if the SM description is complete.
- Detector R&D is in good shape, no serious outstanding questions on technology.
- The features of BTeV make it a nearly ideal B experiment:
  - Massive statistics from a hadron collider
  - Excellent particle ID, great π^0 and γ reconstruction
  - Flexible and open trigger allows us to adapt easily
- We will make key measurements in B_s^0 decays and states with γ's; our ability to record all b states gives us the broadest possible scope and significant advantages over other experiments
- Part of a high precision flavor program to complement and interpret any NP discoveries at Tevatron or LHC.

Backup Slides

BTeV Compared to B-factories

- No B_s^0, B_c^+, Λ_b^0 at B-factories
- Tevatron σ 10^5 higher than e^-e^+
  - B-factory: $\mathcal{L} = 10^{34} \rightarrow 1.1 \times 10^8\ B^0/10^7$ s
  - BTeV: $\mathcal{L} = 2 \times 10^{32} \rightarrow 1.5 \times 10^{11}\ B^0/10^7$ s
- Reconstruction and tagging efficiency is sometimes $50\times$ better at e^+e^-
- BTeV is able to overcome this with high cross section
- Many modes BTeV collects $30\times$ e^+e^- statistics/yr
- Assume B-factories reach > 500 fb^{-1}, currently ~ 130
- Super-KEK: Plan to upgrade to $\mathcal{L} = 10^{35}$ in 2007, still not competitive with BTeV in $B\bar{B}$

BTeV Advantages over LHCb

- 132 or 396 ns crossing time vs. 25 ns
- Lower BTeV $p \rightarrow$ shorter detector (hall length $\sim$same)
  - Only one RICH needed, less B-field
  - Smaller size $\rightarrow$ better detectors/$$
- Better EM calorimeter — more comprehensive studies
- DAQ has $20\times$ rate, $5\times$ more *b* decays to "tape"
- Pixel detector allows vertexing at L1
  - Unbiased selection of *b* and *c* decays
  - Will have physics that becomes interesting "on tape"
- Multiple interactions per crossing OK
  - Longer interaction region, pixel vertexing
- Vertex detector in B-field can reject low-momentum tracks

Comparisons with LHCb

Comparisons with prelim. (April 2003) LHCb-light #s. BTeV #s scaled to LHCb BR's.

Mode	BR (10^{-5})	LHCb Untagged		BTeV
		TDR	Light	
$B_s^0 \to D_s^+ \pi^-$ (x_s)	300	86 000	72 000	59 000
$B_s^0 \to D_s^+ K^-$ $(\gamma - 2\chi)$	23	6 000	8 000	5 900

Comparisons with LHCb TDR #s. (Light #s will be similar)

Mode	BR	LHCb		BTeV	
		Yield	S/B	Yield	S/B
$B_s^0 \to J/\psi \eta^{(\prime)}$ (χ)	1.0×10^{-3}	—	—	12 650	> 15
$B^0 \to \rho^+ \pi^-$ (α)	2.8×10^{-5}	2 140	0.8	5 400	4.1
$B^0 \to \rho^0 \pi^0$ (α)	0.5×10^{-5}	880	0.05?	776	0.3

BTeV does better with γ, π^0, more comprehensive data set

396 ns Bunch Crossing

- BTeV was designed for $\mathcal{L} = 2 \times 10^{32}$ cm^{-2}s^{-1} at 132 ns $\rightarrow \langle 2 \rangle$ interactions/crossing
- Now expect $\mathcal{L} \sim 2 \times 10^{32}$ cm^{-2}s^{-1} at 396 ns ($\langle 6 \rangle$ int./cross) or $\mathcal{L} \sim 1.3 \times 10^{32}$ cm^{-2}s^{-1} at 396 ns ($\langle 4 \rangle$ int./cross)
- Verified performance by repeating many simulations at $\langle 4 \rangle$ and $\langle 6 \rangle$ int./cross (without re-optimizing code)
- Key potential problem areas (trigger, EMCAL, RICH) all hold up well based on simulations
- On going work to fully understand the impact of a change to 396 ns, *e.g.* optimizing charge collection for pixel readout
- 264 ns is also a possibility (easier to accomplish)

Change from Two Arms to One

Between our first and second PAC approvals, BTeV was rescoped. However, we also found better ways to do physics, so the effect was not as drastic on our ability to achieve our physics goals:

- Loss of one arm: factor = 0.5
- Gains in dileptons:
  - RICH ID of μ's
  - Proposal: $\mu^+\mu^-$ only, now e^+e^- too
  - Factor = 2.4 (or 3.9) for (di)lepton ID
- DAQ retains full bandwidth, loosen triggers: factor = 1.15
- Same-side $K^\pm$ tagging for B_s^0 only: factor = 1.3
- Bottom line: w.r.t. proposal, factors from 0.58–2.9, most physics is same or better with new assumptions